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ABSTRACT

This study explores the reason why very young infants are unable to respond differentially to faces and the cause for developmental changes in infant face perception by age 3 months. Linear systems analysis (LSA) and the contrast sensitivity function (CSF) were used to estimate the facial pattern information available to 1- and 3-month-old infants. Two hypotheses were examined: young infants are incapable of selectively attending to and utilizing perceptual information picked up from particular aspects of the face; early performance may be significantly limited by insufficient acuity and contrast sensitivity for picking up critical pattern information. The second hypothesis was evaluated by estimating the extent to which acuity and contrast sensitivity limitations constrain available facial pattern information; and by considering whether sensory constraints accounted for the infant's observed performance.
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The Human Face:
A View From the Infant's Eye

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We are working on techniques for estimating the stimulus information available to very young infants when their acuity and contrast sensitivity limitations are taken into account. The infant who responds meaningfully to social stimuli must be able to differentially process those stimuli. Therefore, a question of fundamental importance concerns the extent to which perceptual immaturity imposes constraints upon the course of social development.

The human face is one of the most studied of social stimuli in infant research. Recognition and discrimination of particular faces plays an important role in many theories of affective and social development. Furthermore, the meaningfulness of the face makes it a potentially potent stimulus for studying some aspects of perceptual and cognitive development. An infant's ability to respond discriminatively to faces increases during the first several months (Gibson, 1969). Visual scanning of faces shifts from the scanning of external contours almost exclusively at 1 month, to include the scanning of internal contours, such as the eyes and mouth, at 3 months (Haith, Bergman, & Moore, 1977; Maurer & Salapatek, 1976). From birth to 6 months, infants become more capable of discriminating normal faces from so-called scrambled faces (Fantz & Nevis, 1967; Haaf & Bell, 1967; Kagan, 1971), more realistic from less realistic representations of faces (Fagan, 1972, 1974), and finally one face from another (Cornell, 1974; Fagan, 1972). During this time they also become better at discriminating one facial expression from another (LaBarbara, Izard, Vietze, & Parisi, 1976; Young-Browne, Rosenfeld, & Horowitz, 1977).

Despite the large literature on infant face perception, a fundamental question remains unanswered: What is the cause of the inability of very young infants to respond differentially in the abovementioned studies? Two general

hypotheses seem reasonable: 1) Early performance may be limited by the failure of young infants to selectively attend to and utilize the perceptual information they pick up from particular aspects of the face. In other words, appropriate or adequate responses to social stimuli would be limited by the inability to utilize available perceptual information. 2) Early performance may be significantly limited by insufficient acuity and contrast sensitivity for the pick-up of critical pattern information from faces. Adequate social responses would be limited by the inability to detect and discriminate the meaningful aspects of the face. In this study we evaluated the second hypothesis by attempting to estimate the extent to which acuity and contrast sensitivity limitations constrain the pattern information available from faces, and then considering whether these sensory constraints could account for the infant's observed performance.

We found that the information in faces available to 1-month olds permits discernment of only the grossest features: the outer contour defined by the hairline and vague darker areas in the region of the eyes and mouth. By 3 months the information available may permit the detection of differences between highly distinctive facial expressions, such as surprise and sadness, but is unlikely to be sufficient for detection of more subtle differences. Reliable cues for discriminating one face from another are not likely to be available either.

METHOD

In our approach we utilized linear systems analysis (LSA) and the contrast sensitivity function (CSF) (Cornsweet, 1970). LSA has been successfully used to partially characterize the auditory and visual systems of adults. The approach

is based on Fourier's theorem which states that any sound, in the case of audition, or any two-dimensional pattern, in the case of vision, can be exactly described by its frequency components. For an example of how LSA works, consider a stereo system. Suppose we wish to characterize how well a particular stereo reproduces any arbitrary sound. From Fourier's theorem we know that any sound can be represented by a set of sine waves consisting of pure tones of different frequencies, amplitudes, and phases. Thus, if we first independently measured the response of the stereo to sine waves of different frequencies, we could quantitatively predict how each of the sine wave components of any sound would be reproduced by the stereo, and thereby predict the stereo's response to the sound. In practice, this procedure works exceedingly well for linear or nearly linear systems such as stereos. The same approach can be used to characterize the visual system's response to two-dimensional patterns. By Fourier's theorem, any two-dimensional pattern can be exactly characterized by a set of sine wave components of various spatial frequencies, contrasts, and orientations. The first figure shows two such sine wave components. Spatial frequency refers to the number of stripes in one degree of visual angle: the sine wave grating on the right is higher in

 Insert Figure 1 about here

spatial frequency than the one on the left. Contrast refers to the ratio of the intensities of adjacent light and dark stripes. Both gratings in the figure are of fairly high contrast. Orientation refers to the tilt of the sine wave gratings. Both gratings are vertical.

One can estimate the ability of the visual system to process different sine wave gratings by measuring a person's sensitivity to gratings of different spatial frequencies. The function which describes this is called the contrast sensitivity function (CSF). The second figure shows a typical adult CSF which represents sensitivity for a variety of spatial frequencies. For comparison, an actual sine wave grating is shown above the CSF graph. The

 Insert Figure 2 about here

spatial frequency of the grating increases from left to right and its contrast increases from top to bottom. Note that your sensitivity to the grating varies with spatial frequency; peak sensitivity to the grating is at an intermediate frequency, and as spatial frequency gets very high, you become unable to see the sine wave grating at even the highest contrast.

Once one knows the CSF of a visual system, LSA can be used to predict how the image associated with particular two-dimensional patterns will be modified in passing through the system. Actually for the application of LSA to be rigorous, the visual system under study must satisfy the preconditions of LSA. The adult visual system does not exactly satisfy these preconditions, but LSA still appears to provide reasonable predictions. The same is likely to be true for infants.

Three groups of investigators have measured CSF's in 1-, 2-, and 3-month olds (Atkinson, Braddick & Moar, 1978; Banks & Salapatek, 1978; Pirchio, Spinelli, Fiorentini, & Maffei, 1978). The third figure shows some of the

 Insert Figure 3 about here

data from the Banks and Salapatek experiment. The average CSFs for 1-, 2-, and 3-month olds are shown. Note that considerable change occurs from 1 to 3 months. Maximum sensitivity is greater at 3 months and the high frequency cutoff (highest detectable frequency) is at a higher spatial frequency. Note also that these CSFs are very different from those of the adults. Figure 4

 Insert Figure 4 about here

shows the 2-month CSF again and a typical adult CSF for similar stimulus conditions. The peak sensitivity of the infant function is about 25 times lower in sensitivity than the peak of the adult function. The highest detectable spatial frequency is about 12 times lower for the infants than for adults. All of this implies that the pattern information young infants are able to pick up is considerably less than the information available to adults. A convenient way to represent this is the contrast reduction function (Fig. 5). The ratio of adult to infant contrast sensitivity is plotted for various spatial frequencies.

 Insert Figure 5 about here

In the experiment we are reporting today, we used these CSFs and linear systems analysis to estimate the pattern information from faces that is available to 1- and 3-month infants. The stimuli we used were front-view photographs of a number of faces. For two faces, one male and one female, a series of different facial expressions were photographed. We could manipulate the spatial frequency content of the photographs using a device called an optical Fourier analyzer (Figure 6), commonly used in physical optics. This device

 Insert Figure 6 about here

consists of a laser and a series of lenses. Laser light passing through photographic slides of the faces is broken up into its spatial frequency components by one set of lenses. It is then reconstructed by a second set. Between the first and second sets we filtered out certain spatial frequencies using a function which passes all frequencies below the cutoff point (vertical arm in figure 5) and blocks all frequencies above the cutoff point. The cutoff frequencies for 1- and 3-month olds were 2 and 3 cycles/degree respectively. We then reduced the contrast in the photographs in accordance with the average contrast reduction for the spatial frequencies remaining after filtering (the horizontal arm of the rectangular function in figure 5). This was a 45-fold reduction for 1-month olds and 25-fold for 3-month olds.

Figure 7 and 8 show the resulting photographs for a woman exhibiting three

 Insert Figure 7 and 8 about here

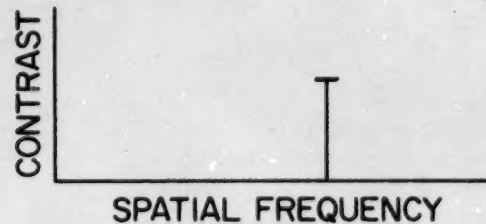
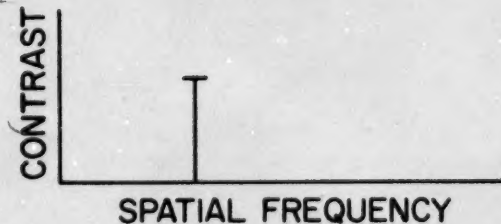
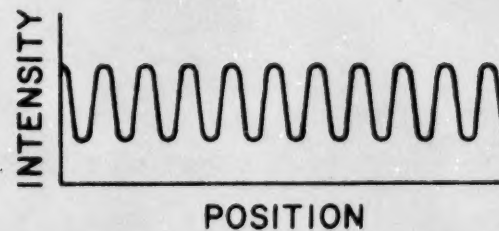
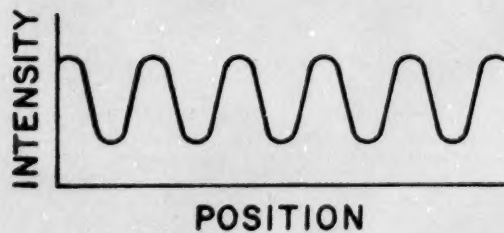
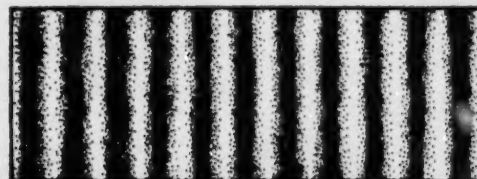
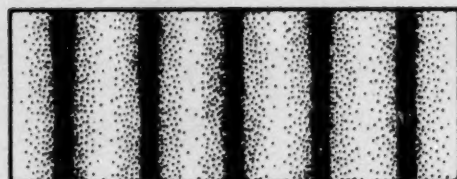
different facial expressions. The photographs should be viewed from a distance of six inches for the spatial frequency content to be appropriate for 1- and 3-month olds respectively. On the left in each figure the woman has a frowning expression, in the center she is smiling, and on the right she is showing surprise. Figure 7 was spatial-frequency filtered and contrast-reduced in accordance with the 1-month-old contrast sensitivity function. The pattern information available consists primarily of an external contour. Very faint areas of contrast in the region of the eyes and mouth may be discerned. The different facial expressions are difficult to discriminate. Figure 8 shows the effect

of contrast reduction and spatial-frequency filtering in accordance with the 3-month contrast sensitivity function. The internal aspects of the face are more prominent in this Figure. All the expressions are discernible although the expression of surprise is more distinctive than the other two expressions. Gross changes in the eyes (e.g., open or closed) and the configuration of the mouth are also apparent.

In conclusion, we would predict that purposive scanning of the interior regions of the face would be unlikely in 1-month olds. Moreover, due to the relative prominence of the external contour in the 1-month Figure, we would also predict a tendency by very young infants to lock their gaze on outer contours. Both of these phenomena have been observed in 1-month olds (Maurer & Salapatek, 1976; Haith et al., 1977; Hainline, 1978).

Figure 8 suggests that by 3 months, contrast differences between an open and closed mouth are likely to be discernible, which would provide pattern information for discrimination of the expression of surprise. However, more subtle differences, as in a smile and frown, may not be reliably discernible by the 3-month old. These results predict the finding of Young-Browne, Rosenfeld, and Horowitz (1977) that the expression of surprise is differentially discriminable by 3-month olds.

It seems to us that awareness of the social significance of the human face must therefore await sufficient maturity of the visual system. One-month olds do not appear to have the visual sensitivity to detect important aspects of patterns as complex as faces (Bronson, 1974). One-month olds' reactions which have been interpreted to have social significance may be explained more parsimoniously in terms of the pattern information available from visual stimuli in general.



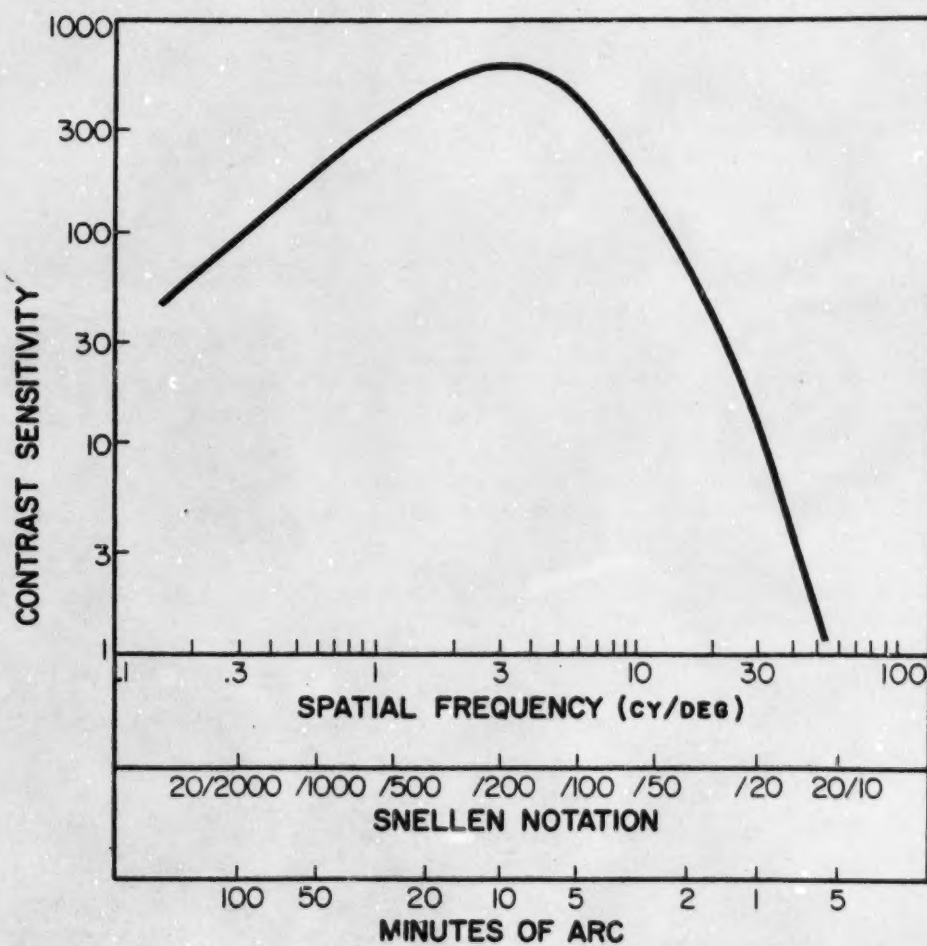
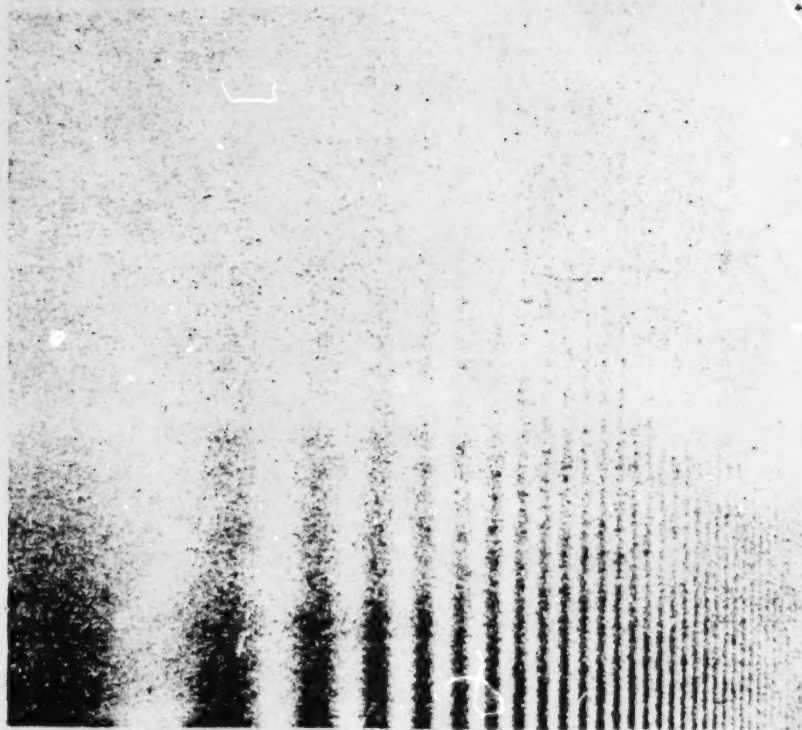


Figure 2

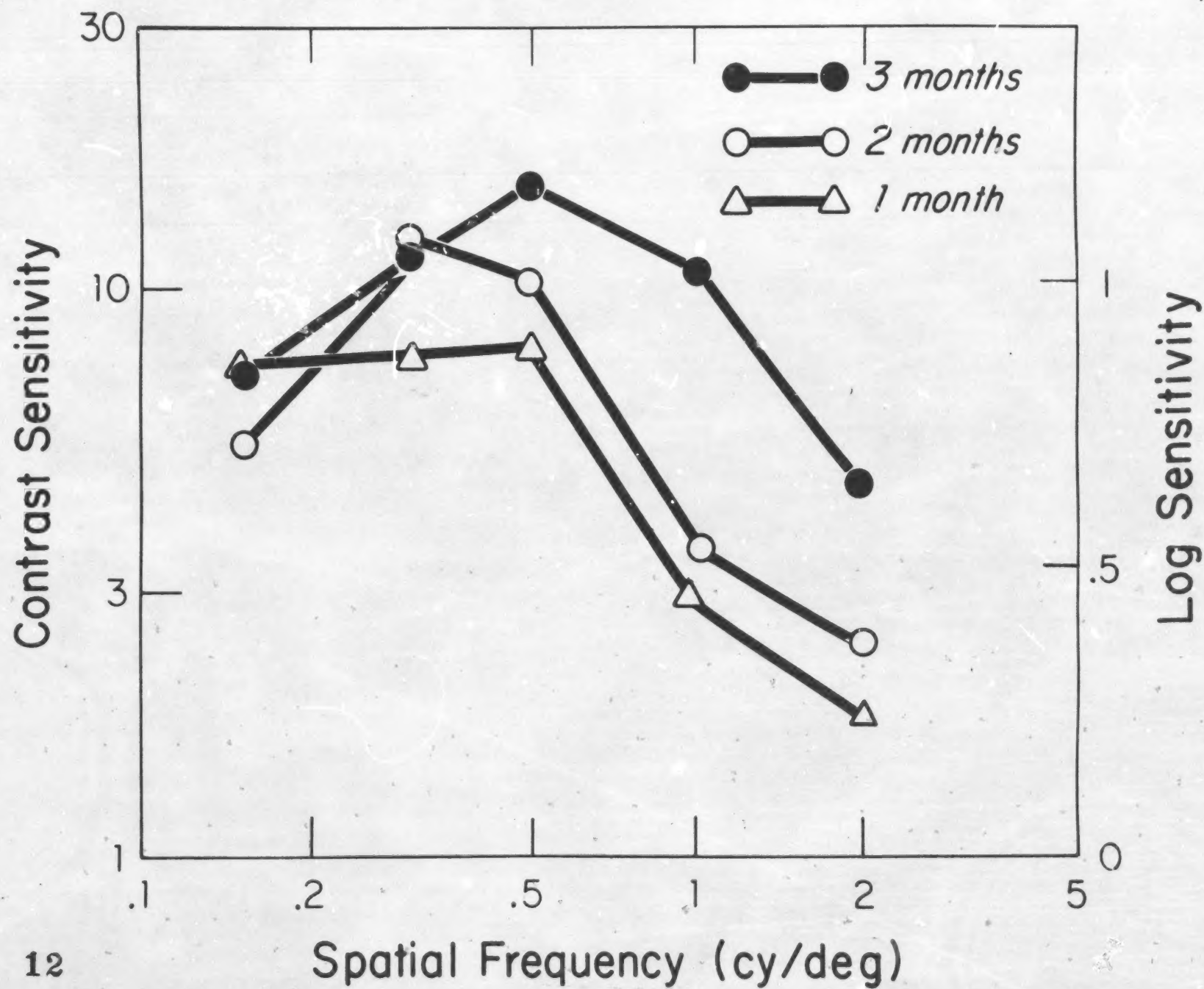


Figure 3

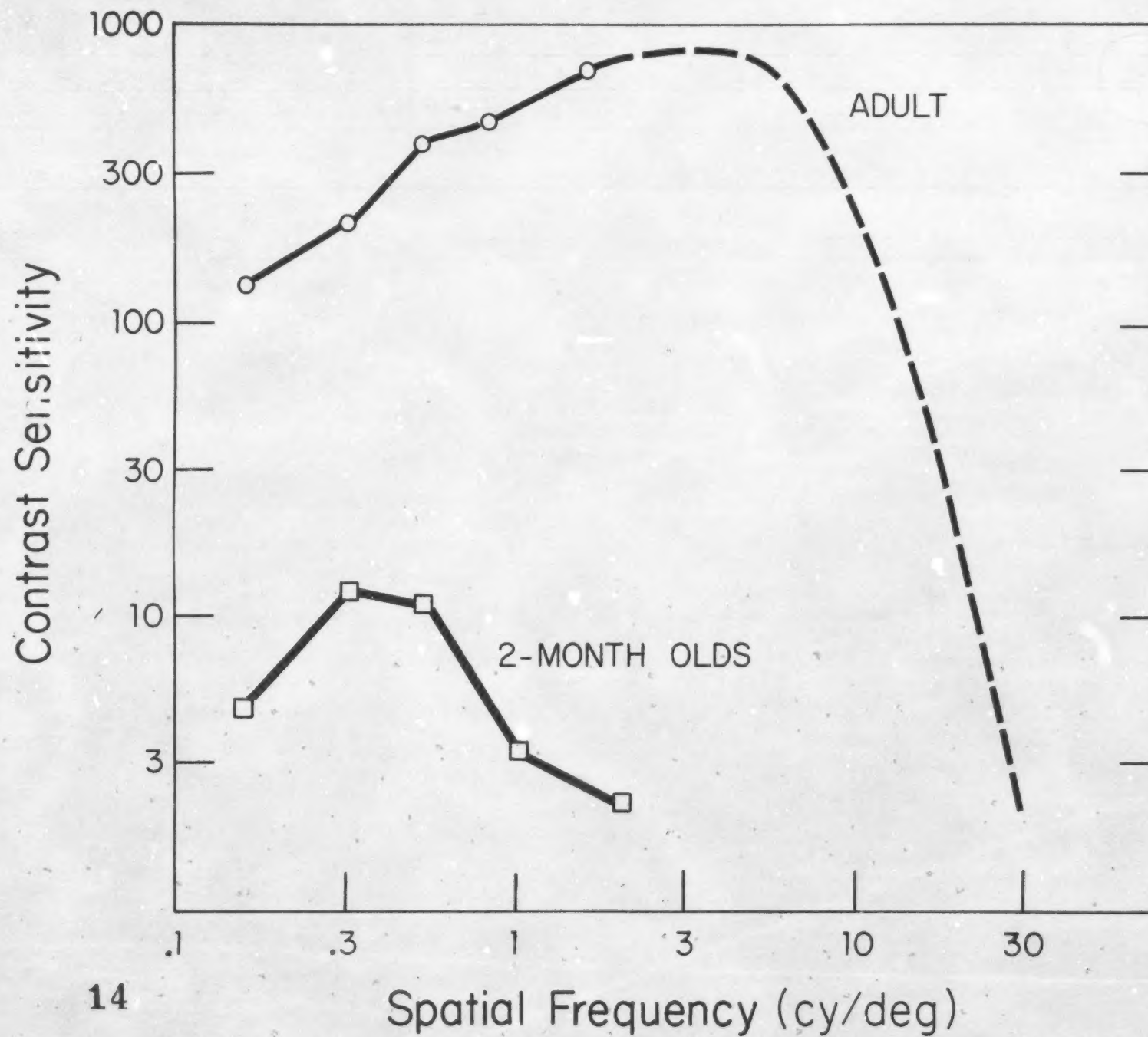


Figure 4

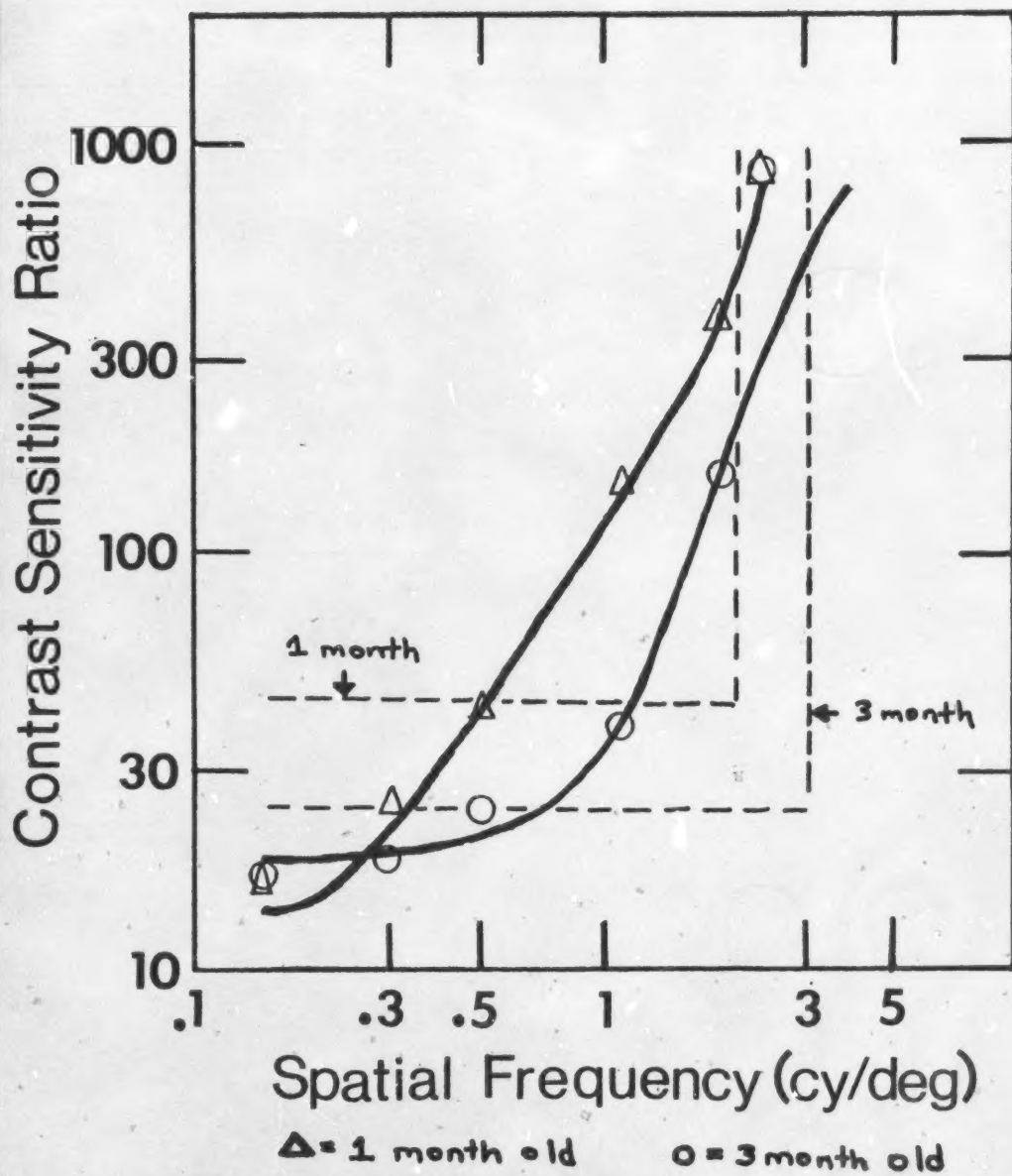


FIGURE 5

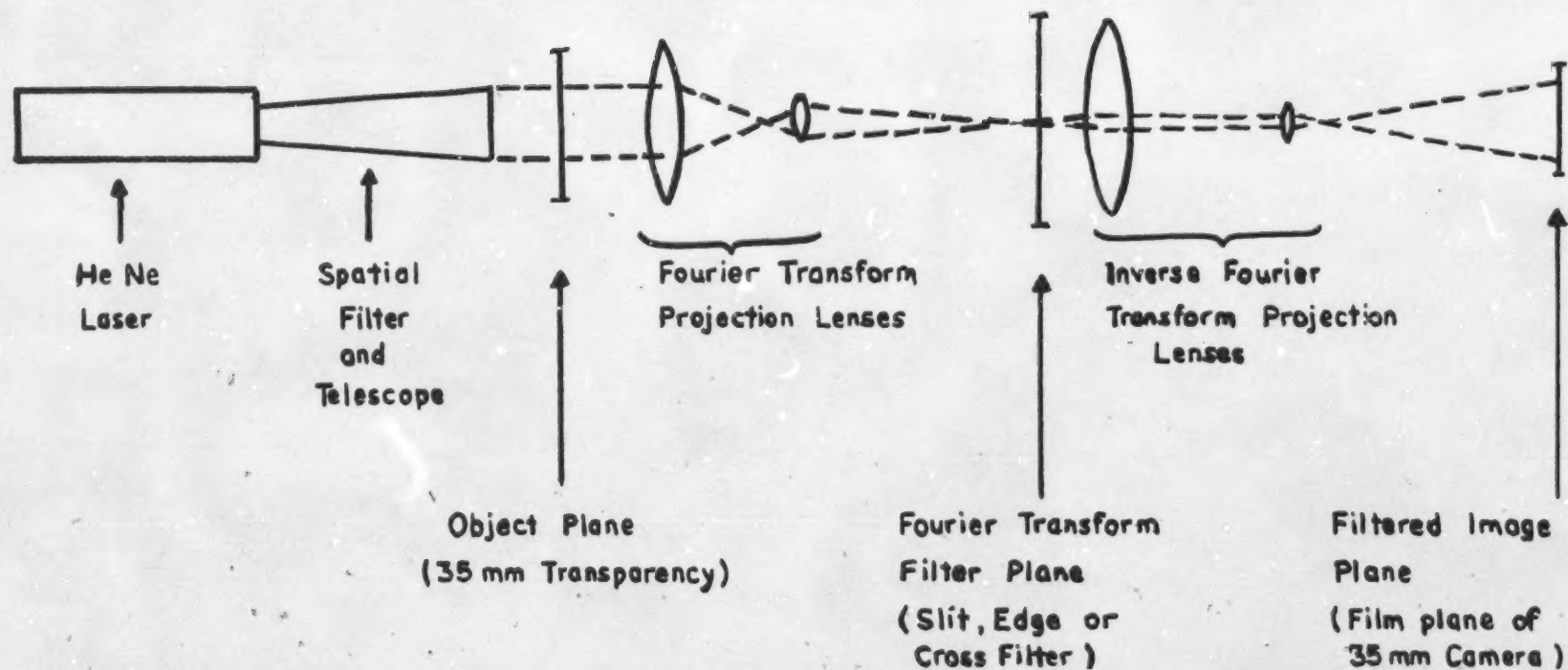


Figure 6

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